# Future irrigation water requirements in the Ijuí River basin, RS

Kayoma K. da Silva[1], Tirzah M. Siqueira[1], Katiucia N. Adam[2],
Andréa S. Castro[1], Luciara B. Corrêa[1] & Diuliana Leandro[1]

[1] Universidade Federal de Pelotas/Centro de Engenharias/Curso de Engenharia Ambiental e Sanitária. Pelotas, RS. E-mail: kayomakarpinski@gmail.com; tirzahmelo@hotmail.com (Corresponding author); andrea.castro@ufpel.edu.br; luciarabc@gmail.com; diuliana.leandro@gmail.com
[2] Universidade Feevale/Instituto de Ciências Exatas e Tecnológicas/Curso de Engenharia Civil. Novo Hamburgo, RS. E-mail: katiucia@feevale.br

**A B S T R A C T**

Changes in temperature and precipitation intensity and frequency have influenced the water demand for irrigation. Regions that have agriculture-based economies, as in the Ijuí River basin, are often affected by periods of drought or excessive rainfall, which is harmful for agricultural productivity. This study aimed to evaluate future irrigation water demands of four crops in this basin (bean, corn, wheat and soybean), comparing them with a baseline period. Meteorological data forecasts were obtained from the regional climate model ETA 40 CTRL for the climatic scenario A1B, for the baseline (1961-1990) and future (2011-2100) periods. The one-dimensional SWAP model was used to estimate the water demand for irrigation. The results showed that, in the future, irrigation water requirements will be smaller for all crops. In the short term (2011-2040), water demands were similar to those for the baseline period, but from the middle of the century onwards (2041-2100), greater reductions were observed.

# Demandas futuras de água para irrigação na bacia hidrográfica do rio Ijuí, RS

**R E S U M O**

A alteração de temperatura e da intensidade e frequência dos índices pluviométricos tem influenciado a demanda de água para irrigação. Regiões que possuem sua economia voltada para a agricultura, como na bacia hidrográfica do rio Ijuí, são frequentemente afetadas por períodos de estiagem ou de excesso de chuva que prejudicam a produtividade agrícola. O presente trabalho teve como objetivo estimar as demandas futuras de água para irrigação em quatro culturas nesta bacia (feijão, milho, trigo e soja), comparando com um cenário atual. Os dados das projeções meteorológicas foram obtidos por meio do modelo climático regional ETA 40 CTRL, em um cenário futuro A1B, referentes ao período atual (1961-1990) e futuro (2011-2100). O modelo unidimensional SWAP foi utilizado para simular as demandas de água para irrigação. Os resultados mostraram que no futuro a necessidade de irrigação será menor para todas as culturas analisadas. Em curto prazo (2011-2040), as demandas se mantiveram próximo ao período atual. Contudo, da metade do século em diante (2041-2100) houve maiores reduções.

## INTRODUCTION

Climate change is mainly caused by the increasing emissions of greenhouse gases (GHG) derived from human activities, such as the burning of fossil fuels and deforestation, as well as from natural events such as volcanic eruptions (IPCC, 2013).

According to the Intergovernmental Panel on Climate Change (IPCC), in 2011, the concentrations of $CO_2$ and $CH_4$ in Earth's atmosphere were 391 ppm and 1803 ppb, respectively, representing increases of 40 and 150%, respectively, compared to the preindustrial era (IPCC, 2013). Besides the increase in temperature, greater frequency and intensity of extreme events, changes in rainfall regimes, changes in evaporation rate, and transpiration may also negatively affect agriculture (Yoo et al., 2012).

These changes have impacted the productivity and quality of the agricultural sector, because of their influences on crop development. The Brazilian state of Rio Grande do Sul (RS), whose economy is mainly based on agriculture, has already suffered significant losses in production owing to the occurrence of extreme events. According to the Economic and Statistics Foundation (FEE), in 2012, the economy of RS decreased 2.1%, strongly affected by droughts, which imposed severe losses both to agriculture (-43.3%) and the manufacturing industry (-5.4%).

In this context, there is concern about how future climatic events may affect agriculture in the Ijuí River basin, which is located in the northwest mesoregion of RS. The economic activity of this region is focused in the primary sector, with the predominance of non-irrigated crops, such as soybean and corn (SEMA, 2007).

Therefore, the objective of this study was to estimate and compare the current and future water requirements for irrigation of normally non-irrigated crops in the Ijuí River basin, RS, using the SWAP model and meteorological projections generated by climate models.

## MATERIAL AND METHODS

The Ijuí River basin is located in the northwest region of Rio Grande do Sul (Figure 1) between the coordinates 27° 45' S and 26° 15' S of latitude and 53° 15' W and 56° 45' W of longitude and has a drainage area of 10,649.13 km². The Ijuí River is one of the main tributaries of the left bank of the Uruguay River Basin (Pereira et al., 2014).

The land use is mainly agriculture, with the practice of direct cultivation, with soybean, maize, and wheat as the main crops. Bean, soybean, and corn are cultivated during the spring and summer, and wheat and oat are the main crops during the winter (Melo et al., 2015).

According to Wollmann & Galvani (2012), the climate is classified as Cfa, based on Köppen's classification, with annual average temperature ranging from 17 to 20 °C and average annual rainfall ranging from 1,700 to 1,800 mm.

Meteorological data were obtained from the regional climate model ETA 40 CTRL (control member), based on the future climatic scenario A1B, and provided by the National
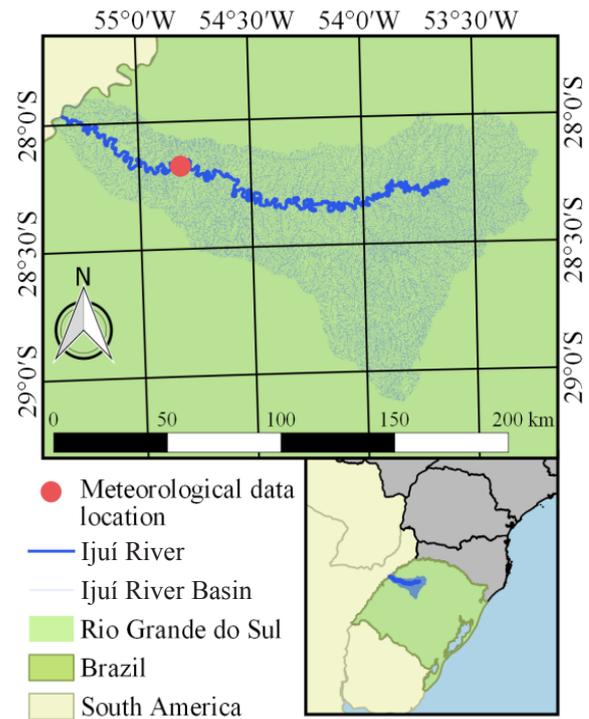


Figure 1. Ijuí River basin location and meteorological data location

Institute for Space Research, INPE (Chou et al., 2012; Marengo et al., 2012).

The A1B scenario is one of the A1 scenarios that describes a future world in which globalization is dominant, with rapid economic growth, small population increase, and rapid development of more efficient technologies, and it considers intermediate GHG emissions compared to other scenarios (IPCC, 2007).

The daily meteorological variables used in the simulations with the SWAP model were precipitation (P; mm), air vapor pressure (U; kPa), minimum and maximum temperatures ($T_{min}$ and $T_{max}$, °C), wind speed (V; m s⁻¹), and solar radiation (R; KJ m⁻²).

Figure 1 indicates the location (28° 18' W of latitude and 54° 83' S of longitude) for where these meteorological variables of current (1961-1990) and future (2011-2100) periods were projected. The future period was divided into three subperiods: short term (2011-2040), medium term (2041-2070), and long term (2071-2100), which are hereafter represented by the central year of each period: 2025, 2055, and 2085, respectively.

**SWAP model**

Water balance in a soil profile is determined by the numerical solution of the Richards equation in the form:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[ K_{(\psi)}\left( \frac{\partial \psi}{\partial z} + 1 \right) \right] - S_a(\psi) \qquad (1)$$

where:

$\theta$    - soil volumetric moisture, cm³ cm⁻³, associated with a given matrix potential $\psi$, cm;

$K_{(\psi)}$    - soil hydraulic conductivity, cm d⁻¹;

t    - time, d;

z    - soil profile depth, cm; and,

$S_a(\psi)$ - term referring to water extraction by plant roots, d⁻¹.

As agricultural crops adopted in this study are non-irrigated, it was assumed that all water required by the plant will be supplied, thus:

$$IWR = T_c - T_a \quad (2)$$

where:

IWR - irrigation water requirement, cm;
$T_c$ - potential transpiration, cm; and,
$T_a$ - actual transpiration, cm.

The SWAP model calculates evapotranspiration for a reference crop based on the Penman–Monteith equation, assuming a plant height of 0.12 m; fixed surface strength of 70 s m$^{-1}$; and albedo equal to 0.23. From $ET_{ref}$, the evapotranspiration rate is calculated for a crop of interest ($ET_c$), using the crop factor ($\kappa_c$).

$$ET_c = \kappa_c \cdot ET_{ref} \quad (3)$$

In sequence, the values of crop potential transpiration ($T_c$) and soil evaporation ($E_p$) are separated using the leaf area index (LAI). The potential evaporation is then calculated by:

$$E_p = E_{p0}(1 - W_{frac})e^{-\kappa_{gr}LAI} \quad (4)$$

where:

$W_{frac}$ - fraction of the day when the crop is wet, dimensionless;
$E_{p0}$ - evaporation rate of an exposed wet soil, cm d$^{-1}$; and,
$\kappa_{gr}$ - extinction coefficient for solar radiation, dimensionless.

From Eq. 4, the model calculates $T_c$ by the difference:

$$T_c = ET_c(1 - W_{frac}) - E_p \quad (5)$$

where:

$ET_c$ - total evapotranspiration rate in periods with dry crop, cm d$^{-1}$.

The potential transpiration ($T_c$) is equal to the maximum rate of water extraction by the plant's roots ($S_c$). When it is integrated along the root depth, it provides (Kroes et al., 2008):

$$S_c(z) = \frac{\ell_{root}(z)}{\int_{-D_{root}}^{0} \ell_{root}(z)dz} T_c \quad (6)$$

where:

$S_c(z)$ - potential rate of water extraction by the roots at a certain depth, d$^{-1}$;
$D_{root}$ - root layer thickness, cm;
z - root depth, cm;
$T_c$ - potential transpiration, cm; and,
$\ell_{root}(z)$ - root length density distribution.

The actual transpiration rate $S_a(z)$ is calculated considering some effects of water stress on the crop, so that the potential value $S_c(z)$ is reduced to the actual value $S_a(z)$ by:

$$S_a(z) = \beta \cdot S_c(z) \quad (7)$$

where:

$\beta$ - water stress factor in dry conditions, dimensionless.

Integrating $S_a(z)$ along the root zone, the actual transpiration of the crop is finally given by:

$$T_a = \int_{D_{root}}^{0} S_a(z)dz \quad (8)$$

**Agronomic data**

Table 1 lists the crops considered in this study and their respective cultivated areas. The choice of these crops is mainly because they present a larger cultivated area compared to other crops in the region.

The simulation period was from January 1, 1961 to November 30, 1990 (baseline period) and January 1, 2011 to November 30, 2099 (future period). The agronomic parameters required for simulation with the SWAP model are shown in Table 2.

Table 1. Study crops and their cultivated areas

| Crop | Area (ha) |
| --- | --- |
| Bean | 360 |
| Corn | 5286 |
| Soybean | 14865 |
| Wheat | 2865 |

## Results and Discussion

**Temperature and precipitation projections**

Table 3 presents the mean annual temperature, the annual accumulated precipitation, and their predicted anomalies for the 21st century given by the ETA 40 CTRL climate model. An anomaly refers to the difference between the variable in a future period and its value in the baseline period.

The temperature projections increase for all future periods. According to the IPCC forecasts, the global temperature is expected to increase from 1.2 to 6.4 °C until the end of this century, in comparison to the period of 1961-1990 (IPCC, 2007). In this study, positive temperature anomalies were found, reaching around 5 °C at the end of the century. These changes, in addition to the land use and occupation process, have been considered as the main causes of temporal changes in precipitation and flow (Kliment et al., 2011). Moreover, according to Khalil (2013), this increase in temperature would lead to higher evaporation rates in the hydrological cycle, with implications for ecosystems and agricultural crops.

Pellegrino et al. (2007) simulated scenarios of temperature increases of 1.0, 3.0, and 5.8 °C, associated to an increase in precipitation up to 15% for Brazil, and observed an increase in the unapt area for soybean cultivation in the State of Rio Grande do Sul as the temperature rises. In this sense, global warming may alter areas suitable for planting, and increase the plant water deficit, causing an increase in areas with high climatic risk.

Table 2. Crop agronomic parameters

| Period of simulation* | | Bean Oct. 2-Dec. 25 | Corn Oct. 19-Mar. 2 | Soybean Nov. 16 -Mar. 22 | Wheat May 17-Sep. 16 |
|---|---|---|---|---|---|
| Growing period (days) | | 95 | 128 | 140 | 148 |
| Stages of development (days) | Initial | 20 | 18 | 20 | 18 |
| | Development | 25 | 35 | 35 | 32 |
| | Medium | 30 | 35 | 60 | 48 |
| | Final | 20 | 40 | 25 | 50 |
| Maximum root depth (cm) | | 80 | 140 | 100 | 100 |
| Crop factor ($\kappa_c$) | Initial | 0.35 | 0.34 | 0.40 | 0.42 |
| | Development | 0.65 | 0.70 | 0.90 | 0.82 |
| | Medium | 0.90 | 0.99 | 1.21 | 0.93 |
| | Final | 0.80 | 0.61 | 1.09 | 0.53 |
| Root depth (z) (m) | Initial | 0.1 | 0.1 | 0.1 | 0.3 |
| | Development | 0.3 | 0.8 | 0.5 | 0.3 |
| | Medium | 0.8 | 1.4 | 1.0 | 1.0 |
| | Final | 0.8 | 1.4 | 1.0 | 1.0 |
| Leaf area index (LAI) | Initial | 0.1 | 0.1 | 0.1 | 0.1 |
| | Development | 1.5 | 2.5 | 3.0 | 1.7 |
| | Medium | 4.0 | 4.8 | 7.0 | 4.7 |
| | Final | 2.0 | 2.0 | 1.5 | 1.7 |

*The total duration of the cultivation period was given by the sum of all stages of crop development. However, only half of the final development stage was adopted because plants only need water supply during the first half of this period without inhibiting their development

Table 3. Mean annual temperature and mean annual accumulated precipitation projected by the ETA 40 CTRL model*

| Period | Mean temperature | Temperature anomaly | Mean accumulated precipitation | Accumulated precipitation anomaly |
|---|---|---|---|---|
| | (°C) | | (mm) | |
| Baseline | 17.6 | - | 1866 | - |
| 2025 | 20.9 | 3.3 | 1912 | 47 |
| 2055 | 21.9 | 4.2 | 2053 | 187 |
| 2085 | 22.6 | 5.0 | 2181 | 316 |

*Each value in the table corresponds to the mean of each 30 years period (baseline or future)

With respect to precipitation, the anomaly of the period of 2025 presented lower fluctuation than the subsequent periods. A higher increase in rainfall rates is expected between the periods of 2055 and 2085, and the greatest anomaly is expected by the end of the century. This increase of precipitation can impact river flow in the basin, which is a determinant factor in the occurrence of floods and the availability of water for public supply and irrigation.

**Future irrigation water requirements (IWRs)**

Table 4 presents the values of baseline and future irrigation water requirements (IWRs). Each value refers to the cumulative average for each period of 30 years, obtained with the SWAP model. IWR anomalies ($\Delta_a$) are also presented, with the values in parentheses referring to the percentages of these anomalies compared to the baseline period.

As can be seen, negative values indicate a reduction of irrigation demands for all crops throughout the century. These results are due to the increase in cumulative mean precipitation found for all periods. It is also observed that soybean presented greater demand of water when compared to the other crops. Higher irrigation water demands may be related to the fact

that this crop is produced in the summer, a season with lower rainfall and higher temperatures in the State, leading to an increase in plant transpiration rates.

For bean, there may be a significant drop in water demand in the periods of 2055 and 2085, with a reduction of about 83%. According to Back (2001), bean is sensitive to water stress and has a reduced recovery capacity because of its underdeveloped root system. In this sense, irrigation should be well planned to avoid excess water in the soil, which causes crop damage.

Regarding wheat, water demand could be reduced by about 91% in 2025, 78% in 2085, and 7% in 2055. In 2055, there was a small demand reduction, which was influenced by factors other than precipitation. It is possible that higher accumulated values of precipitation are concentrated in months that are not interesting in an agronomic point of view in the region, and additional studies on rainfall distribution are needed throughout the year.

Figure 2 shows the variability of IWR for all periods analyzed, which are 30 years each. It is observed that soybean presents greater water deficits in some years of the 2025s in relation to other future periods, having peaks near or higher than the baseline period. However, when compared to the

Table 4. Mean future irrigation water requirements (IWRs) and anomalies ($\Delta_a$)*

| Crop | Baseline | IWR (cm) (2025) | IWR (cm) (2055) | IWR (cm) (2085) | $\Delta_a$ (cm) (2025) | $\Delta_a$ (cm) (2055) | $\Delta_a$ (cm) (2085) |
|---|---|---|---|---|---|---|---|
| Bean | 1.85 | 1.01 | 0.31 | 0.31 | -0.84 (-45) | -1.54 (-83) | -1.54 (-83) |
| Corn | 1.90 | 1.49 | 0.44 | 0.54 | -0.41 (-22) | -1.46 (-77) | -1.36 (-72) |
| Soybean | 7.59 | 5.65 | 4.25 | 2.64 | -1.94 (-26) | -3.34 (-44) | -4.95 (-65) |
| Wheat | 0.49 | 0.04 | 0.45 | 0.11 | -0.44 (-91) | -0.03 (-7) | -0.38 (-78) |

* Values in parentheses represent percentage

A.

B.

C.

D.
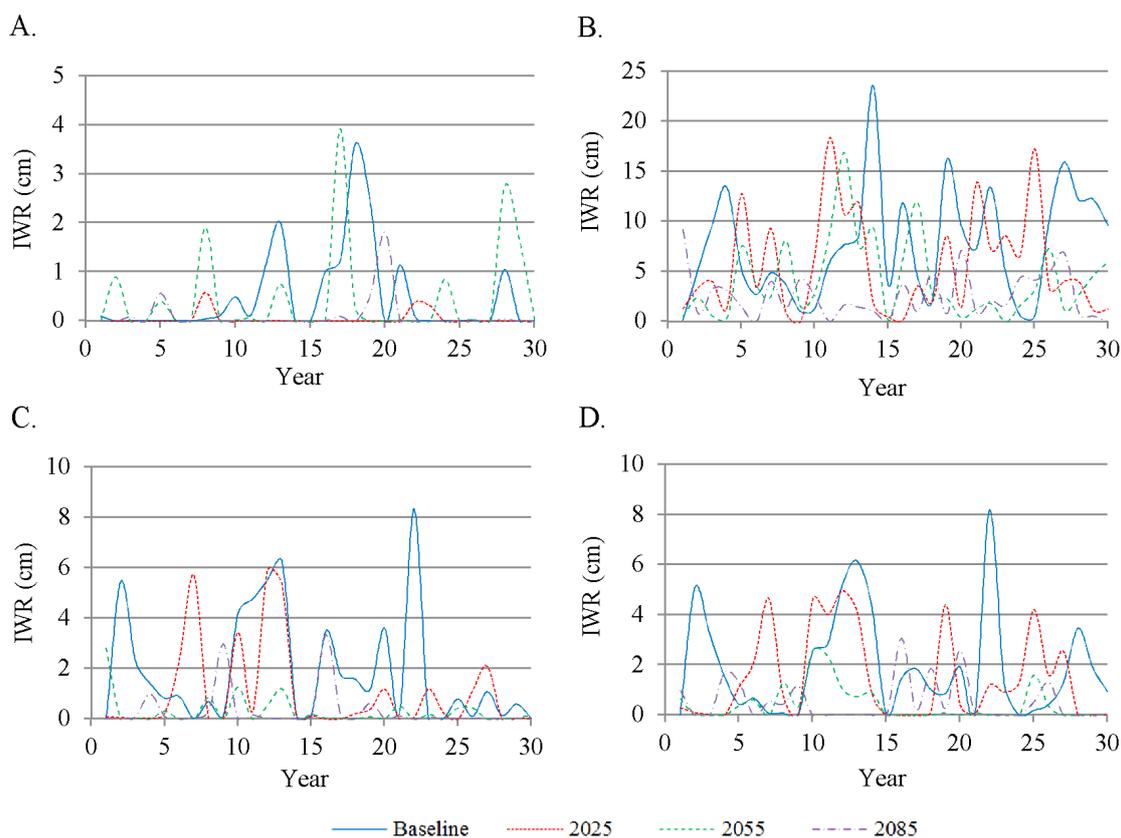


Figure 2. Current and future irrigation water requirements (IWR) for wheat (A), soybean (B), bean (C), and corn (D)

average, the irrigation water demand remains lower than that of the comparison period.

Wheat showed a higher IWR peak in 2055 (3.93 cm) compared to the current period (3.61 cm). There are years when the future water demand exceeds the baseline period, and this result is not identifiable in terms of means and anomalies (Table 4). The periods 2025 and 2085 showed very low IWR, with only one peak of almost 2.0 cm in 2085. This is because wheat is grown in winter when precipitation is higher.

These results indicate decreasing demands throughout the century, with significant differences between future and baseline periods. For the state of Rio Grande do Sul, such indications favor soybean production; however, it is important to remember that the impacts of increasing precipitation can be compensated by an increase of temperature from higher evapotranspiration rates (Melo et al., 2014). Moreover, this increase may cause greater occurrence of extreme events, such as hail storms, leading to the destruction of crops.

For the bean crop, the highest peak of IWR also refers to the period of 2025, with higher water requirements in the short term. This is in accordance with the projection of accumulated average precipitation, which, in this period, presented lower values when compared to the other periods. In 2055, there was no expressive IWR, and the production will probably be little affected by variations in the rainfall regime. However, according to Wada et al. (2013), future water demands for irrigation (IWR) are subject to great uncertainties owing to anticipation of climate and changes in precipitation variability.

In the case of corn, there was a reduction of water demands for the periods of 2055 and 2085. In 2025, the crop presented

greater data variability, with some peaks of water demand close to the baseline period (year 12) and others much below it (years 2 and 22). If water deficit occurs in the critical period until the beginning of the grain filling, the recovery of the productive capacity of the crop will not occur satisfactorily and the final production will be severely affected (Melo et al., 2010). This can impair the quality of spike development. Moreover, the increase of night temperatures also influences crop yield by accelerating the crop development and maturity, reducing the period of grain filling and leading to yield losses.

It is worth mentioning that climate change also impacts plant diseases. The incidence of agricultural diseases and pests is influenced by temperature, relative air humidity, and daily leaf wetting, with the latter dependent on precipitation occurrence and duration. These impacts may also minimize or reverse any benefit from the $CO_2$ fertilization effect. Climate alters the susceptibility of the host interacting with pathogens, drives the distribution of the pathogens, and determines ranges of competitor and biocontrol species. Additionally, it also affects the virulence of many pathogens and, in response to changes in climate and their effects on crops and their pathogens, new crop varieties may develop (Fones & Gurr, 2017).

Each year an estimated 10-16% of global harvest is lost to plant diseases. In financial terms, disease losses cost US$220 billion (Chakrabortya & Newton, 2011). Pardey et al. (2013) recently produced a conservative estimate of global wheat yield losses to stem rust of 6.2 million tons yearly for the 1961-1990 period. Stem (black) rust has historically been an important disease of wheat around the world, including South America (Savary et al., 2017).

These results reveal the importance of the analysis of future irrigation water requirements, making possible better cultivation planning in order to obtain maximum productivities and greater sustainability in the use of water resources.

## Conclusions

1. With regard to future periods, in the short term (2011-2040), water demand remained close to that of the past (1961-1990), but from the middle of the century onwards, negative anomalies were found for all crops, indicating a reduction in water demands.

2. If the predictions of the ETA model are confirmed, the changes in the climate can positively affect the region, as irrigation water demand could be smaller in the future than it was in the past. On the other hand, climate projections are not able to determine the likelihood of extreme events such as storms, hail, and frost that can damage crops, leading to crop losses.

## Literature Cited

Back, A. J. Necessidade de irrigação da cultura de feijão no sul do estado de Santa Catarina. Revista de Tecnologia e Ambiente, v.7, p.35-44, 2001.

Chakraborty, S.; Newton, A. C. Climate change, plant diseases and food security: An overview. Plant Pathology, v.60, p.2-14, 2011. https://doi.org/10.1111/j.1365-3059.2010.02411.x

Chou, S. C.; Marengo, J. A.; Lyra, A. A.; Sueiro, G.; Pesquero, J. F.; Alves, L. M.; Kay, G.; Betts, R.; Chagas, D. J.; Gomes, J. L.; Bustamante, J. F.; Tavares, P. Downscaling of South America present climate driven by 4-member HadCM$_3$ runs. Climate Dynamics, v.38, p.635-653, 2012. https://doi.org/10.1007/s00382-011-1002-8

Fones, H. N.; Gurr, S. J. NO$_X$ious gases and the unpredictability of emerging plant pathogens under climate change. BMC Biology, v.15, p.1-9, 2017. https://doi.org/10.1186/s12915-017-0376-4

IPCC - Intergovernmental Panel on Climate Change. Climate change 2007: Synthesis report. Core Writing Team, Pachauri, R. K.; Reisinger, A. ed. Geneva: IPCC, 2007. 104p.

IPCC - Intergovernmental Panel on Climate Change. Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report. Cambridge: Cambridge University Press, 2013. 1536p.

Khalil, A. A. Effect of climate change on evapotranspiration in Egypt. Researcher, v.5, p.7-12, 2013.

Kliment, Z.; Matoušková, M.; Ledvinka, O.; Královec, V. Trend analysis of rainfall-runoff regimes in selected headwater areas of the Czech Republic. Journal of Hydrology and Hydromechanics, v.59, p.36-50, 2011. https://doi.org/10.2478/v10098-011-0003-y

Kroes, J. G.; Dam, J. C. van; Groenendijk, P.; Hendriks, R. F. A.; Jacobs, C. M. J. SWAP version 3.2 - Theory description and user manual. Wageningen: Alterra, 2008. 262p.

Marengo, J. A.; Chou, S. C.; Kay, G.; Alves, L. M.; Pesquero, J. F.; Soares, W. R.; Santos, D. C.; Lyra, A. A.; Sueiro, G.; Betts, R.; Chagas, D. J.; Gomes, J. L.; Bustamante, J. F.; Tavares, P. Development of regional future climate change scenarios in South America using the Eta CPTEC/HadCM$_3$ climate change projections: Climatology and regional analyses for the Amazon, São Francisco and the Paraná River basins. Climate Dynamics, v.38, p.1829-1848, 2012. https://doi.org/10.1007/s00382-011-1155-5

Melo, T. M. de; Louzada, J. A. S.; Pedrollo, O. C. Impacts of climate change on soybean irrigation water requirements in northwest region of Rio Grande do Sul, Brazil. Irrigation & Drainage Systems Engineering, v.3, p.1-13, 2014. https://doi.org/10.4172/2168-9768.1000129

Melo, T. M. de; Louzada, J. A. S.; Pedrollo, O. C. Trends in extreme indices and seasonal analysis of precipitation and temperature in the northwest region of Rio Grande do Sul, Brazil. American Journal of Climate Change, v.4, p.187-202, 2015. https://doi.org/10.4236/ajcc.2015.43015

Melo, T. M. de; Wottrich, I.; Louzada, J. A.; Helfer, F. Avaliação do atendimento da demanda hídrica da cultura do milho através da subirrigação. Revista Brasileira de Agricultura Irrigada, v.4, p.226-233, 2010. https://doi.org/10.7127/rbai.v4n400034

Pardey, P. G.; Beddow, J. M.; Kriticos, D. J.; Hurley, T. M.; Park, R. F.; Duveiller, E.; Sutherst, R. W.; Burdon, J. J.; Hodson, D. Right-sizing stem-rust research. Science, v.340, p.147-148, 2013. https://doi.org/10.1126/science.122970

Pellegrino, G. Q.; Assad, E. D.; Marin, F. R. Mudanças climáticas globais e a agricultura no Brasil. Revista MultiCiência, v.8, p.139-162, 2007.

Pereira, M. A. F.; Kobiyama, M.; Castro, N. M. R. Relação entre a geometria hidráulica e a curva de permanência em estações fluviométricas da bacia hidrográfica do rio Ijuí – RS. Revista Brasileira de Geomorfologia, v.15, p.443-454, 2014.

Savary, S.; Bregaglio, S.; Willocquet, L.; Gustafson, D.; D'Croz, D. M.; Sparks, A.; Castilla, N.; Djurle, A.; Allinne, C.; Sharma, M.; Rossi, V.; Amorim, L.; Beregamin, A.; Yuen, J.; Esker, P.; McRoberts, N.; Avelino, J.; Duveiller, E.; Koo, J.; Garrett, K. Crop health and its global impacts on the components of food security. Food Security, v.9, p.311-327, 2017. https://doi.org/10.1007/s12571-017-0659-1

SEMA - Secretaria Estadual do Meio Ambiente. Relatório anual sobre a situação dos recursos hídricos no estado do Rio Grande do Sul. Porto Alegre: Departamento de Recursos Hídricos, 2007. 71p.

Wada, Y.; Wisser, D.; Eisner, S.; Flörke, M.; Gerten, D.; Haddeland, I.; Hanasaki, N.; Masaki, Y.; Portmann, F. T.; Stacke, T.; Tessler, Z.; Schewe, J. Multimodel projections and uncertainties of irrigation water demand under climate change. Geophysical Research Letters, v.40, p.4626-4632, 2013. https://doi.org/10.1002/grl.50686

Wollmann, C. A.; Galvani, E. Caracterização climática regional do Rio Grande do Sul: Dos estudos estáticos ao entendimento da gênese. Revista Brasileira de Climatologia, v.11, p.87-103, 2012. https://doi.org/10.5380/abclima.v11i0.28586

Yoo, S. H.; Choi, J. Y.; Nam, W. H.; Hong, E. Analysis of design water requirement of paddy rice using frequency analysis affected by climate change in South Korea. Agricultural Water Management, v.112, p.33-42, 2012. https://doi.org/10.1016/j.agwat.2012.06.002